Bedforms Generated by Turbidity Currents in Continental Margins

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LONG-TERM GOAL

Our long-term scientific goal is to develop sound theoretical models for submarine sediment movement that can be used to predict the initiation, spatial development, and time duration of mud flows and turbidity currents. Of particular interest are the characteristics of the sedimentary deposits that these flows generate, in particular their capability to develop bed forms and gullies by means of sediment erosion and deposition in continental margins.

OBJECTIVES

This past year we have concentrated on testing the hypothesis that turbidity currents are capable of forming gullies along sloping beds. In particular, our main objective has been to elucidate the role played by flow instabilities at the front of very wide turbidity flows on the formation of submarine channels. A second objective has been to explore, with the help of laboratory experiments, the ability of turbidity currents to generate ripples, dunes and antidunes, along their path.

APPROACH

Our approach has consisted of theoretical work, laboratory experiments, and numerical modeling. The theoretical work has concentrated on a perturbation analysis of the equations of motion for turbidity currents carrying a conservative component such as clay, with the goal of assessing the conditions for which bed instabilities will grow and bedforms will develop. Laboratory experiments have been directed to study the formation of bedforms by three-dimensional turbidity currents emanating from a line source at the head of a model slope. Numerical experiments have been conducted as well, to determine the influence of bottom slope and initial sediment concentration on the genesis of gullies at field scale.

WORK COMPLETED

A linear stability analysis of the equations of motion for turbidity currents (Parker et al., 1986) flowing over a movable sediment bed was completed. A conservative component (i.e. clay) was added to a sand-laden turbidity current. The main goal was to study the growth or decay of small bed-level perturbations in the flow direction. The conditions, as prescribed by the theoretical analysis, were then used to design and conduct a set of laboratory experiments with channelized turbidity currents, with the goal of observing the development or lack of bedforms. Preliminary experiments were also completed in the MARGINS tank, to explore the generation of submarine gullies by 3-D turbidity currents. Also, density (saline) currents were produced in order to analyze the effect of these flows on bed deformation. Investigation of front dynamics (front instabilities) for both turbidity and density (saline) currents, has also been performed using image analysis from videotaped experiments.

To complement and guide the laboratory work with turbidity flows from a line source, a numerical model was set up. The model combines the set of equations for turbidity currents proposed by Parker et al. (1986), with a simple, rule-based cellular model proposed by Murray and Paola (1994) for the modeling of braided streams.

RESULTS

So far, no gullies have been observed in the laboratory. Only bedforms such as three-dimensional ripples and dunes, as well as long-wavelength antidune-like sediment waves were observed in the MARGINS tank; all of them generated by turbidity currents and saline currents emanating from a line source.

A variety of scales were found within the patterns of frontal lobes and clefts observed in turbidity and density currents flowing along a wide channel. Figure 1 shows a fractal representation of these scales, obtained by computing the number N of lobes of a characteristic length λ, for a large number of front images. The fractal exponents (dimension) are found to be slightly different for turbidity and density currents. Also, the life time of some of the relevant scales of lobes for turbidity currents is shown in Figure 2, from where a characteristic velocity scale for frontal processes is derived (slope of the fit), this velocity being similar to the propagation velocity of the front.

Both the theoretical perturbation analysis and the laboratory experiments have shown that clay content in turbidity currents plays an important role in the formation of submarine bedforms.

IMPACT/APPLICATION

Our results have important implications for the recognition of morphological features in the field. Turbidity currents are considered to be the sculptors of many, but not all, submarine canyons. Hence it is reasonable to consider the possibility that gullies could also be the result of turbidity current activity, even though their reproduction in the laboratory has so far being rather elusive (Field et al., 1999). The laboratory experiments have clearly shown the capability of these currents for producing longitudinal small-scale bedforms such as dunes and ripples, as well as long-wavelength antidunes. Such antidunes are thought to be related to interfacial instabilities at the upper boundary of the flow. Understanding the front dynamics is also relevant in order to characterize mixing processes and evolution of frontal instabilities, and their effects on the overall current mechanics. Our understanding of the mechanics of bedforms in continental margins until now has been very limited and we hope that our findings will facilitate both the interpretation of the geologic record as well as the design and placement of submarine structures on stable sediment deposits.

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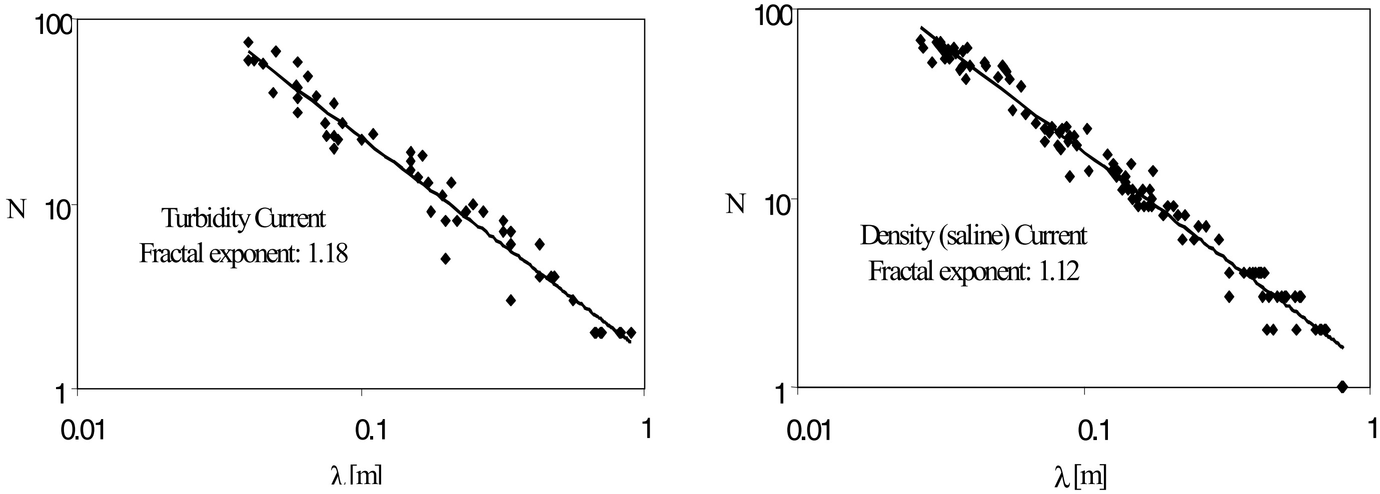

Figure 1. Fractal dimensions for turbidity and density current fronts (frontal roughness).

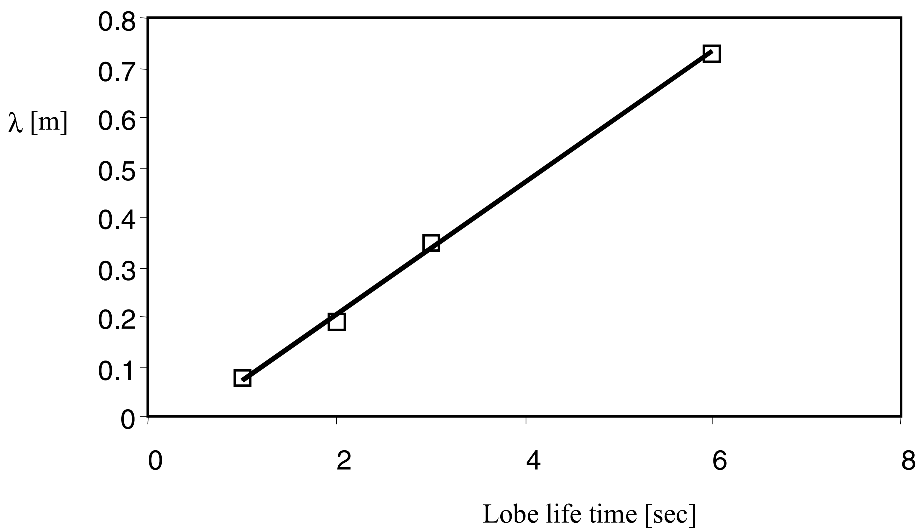

Figure 2. A characteristic velocity scale for frontal processes (instabilities) in turbidity currents is obtained from the slope of the fit.